EXPERIMENTAL STUDY OF SIX-STROKE ENGINE FOR HEAT RECOVERY

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ABSTRACT

This thesis describe about modifying of engine from four stroke engines to six stroke engines. Two more additional strokes are the fifth stroke, which called water injection stroke while the last stroke is called exhaust stroke. Besides, the stroke engine also known as engine two-stroke, four-stroke and also six-stroke which are new things for us. Some modification has to do at the conventional four-stroke to six-stroke. Whereas some of them are modification at the camshaft, which is gear to contact between camshaft and crankshaft with ratio 3:1, shape of plunger, head cover engine and add more other components such as water injector and pump to make the system operate well. After the modification, performance results outcomes are compare with the conventional four-stroke engines. Unfortunately, this engine is not running as well as expected when some problems occur at few part of the engine. To fix the entire problems, analysis has been undertaken to improve some part of the followers, especially since his main problems in their engines. For the future work, the follower must be upgrading the level to get the best design and strength to make sure this engine running well.

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ABSTRAK

Tesis ini menerangkan tentang pengubahsuaian pada enjin empat lejang kepada enjin enam lejang. Dua lejang tambahan adalah pada lejang kelima, yang dipanggil lejang suntikan air manakala lejang yang terakhir dipanggil lejang ekzos. Selain itu, enjin lejan dikenali sebagai enjin dua lejang, empat lejang dan juga enam lejang adalah sesuatu yang baru untuk kita. Manakala sebahagian adalah pengubahsuaian pada aci sesondol, gear yang menyambung di antara aci sesondol dan aci engkol dengan nisbah 3:1, bentuk pelocok, penutup kepala enjin dan ada komponen tambahan seperti suntikan air dan pump untuk membuat sistem itu beoperasi dengan baik. Selepas diubahsuai, hasil keputusan prestasi yang akan membandingkan dengan enjin empat lejang konvensional. Malangnya, enjin ini tidak beoperasi seperti mana yang diharapkan apabila berlaku beberapa masalah berlaku di beberapa bahagian enjin. Untuk menyelesaikan seluruh masalah, analisa telah diambil untuk memperbaiki beberpa bahagian seperti pelocok, terutamanya memberi permasalahan utama kepada enjin. Untuk kerja masa hadapan, pelocok ini harus dinaiktarafkan untuk mendapat reka bentuk yang menarik dan ketahanan untuk memastikan enjin ini beroperasi dengan baik.

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LIST OF SYMBOLS

g_r	Gear Ratio
Cd	Center Distance
d_g	Diameter Gear
d_p	Diameter Pinion
N_g	Number of Teeth in Gear
N_p	Number of Teeth in Pinion
ϕ^n	Normal Pressure Angle
φ	Helical Angle
N	Number of Teeth
d	Pitch Diameter
P_d	Diameter Pitch
	Normal Diameter Pitch
a	Addendum
b	Dedendum
c	Clearance
d_o	Outside Diameter
d_r	Root Diameter
h_t	Total Depth
h_k	Working Depth

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

One of the most difficult challenges in engine technology today is the urgent need to increase thermal efficiency. Six-stroke is one of the solutions for this problem. In the first approach, the engine captures the heat loss from the four-stroke Otto cycle or diesel cycle and uses it to power an additional power and exhaust stroke of the piston in the same cylinder. The pistons in this type of six-stroke engine go up and down six times to complete one cycle in a combustion engine. Fresh water which injected into the cylinder after the exhaust stroke is quickly turned to superheated steam, which causes the water to expand to 1600 times its volume and force piston down for an additional stroke and can reduce the temperature of the engine. As well as extracting power, the additional stroke cools the engine and removes the need for a cooling system making the engine lighter and giving 40 % increased efficiency.

1.2 PROBLEM STATEMENT

Nowadays, all the conventional internal-combustion engines are running in two-stroke and four-stroke. To convert the engine to run in six-stroke, there is a need to do some modification like camshaft modification, crankshaft to camshaft ratio and introducing a new water injection system.

1.2 OBJECTIVES

- To modify the conventional four stroke engine to a six-stroke.
- To compare the new engine performance with conventional one.

1.3 SCOPES

- Characteristic study of two-stroke engine, four-stroke engine and six-stroke engine.
- Crankshaft and camshaft gear design and modification part of the six-stroke engine.
- Run test six-stroke engine and identify the problem at this engine also fix the problem.
- Design new triangle follower and do analysis base on material.
- Carry out performance test.
- To analyze data that has been obtained from the performance test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

An internal-combustion engine is any engine that operates by burning its fuel inside the engine. In contrast, an external combustion engine burns its fuel outside the engine like in a steam engine. The majority of the actual internal-combustion engines, operating on different cycle have one common feature, combustion occurring in the cylinder after each compression, resulting in gas expansion that acts directly on the piston (work) and limited to 180 degrees of crankshaft angle.

The two-stroke internal-combustion engine was first designed by Dugald Clerk. Operation of a two-stroke engine needs only one revolution to complete the cycle. It means that for each movement, it has two cycles running together. The stroke is called the stroke up and stroke down. Thus, from this operation, the engine called two-stroke.

The four-stroke internal-combustion engine was first designed by the Nikolaus August Otto. The basic operating principle of this engine is the conversion of heat energy liberated by the combustion of the fuel into mechanical energy, which rotates the crankshaft. The names of the stroke from the start of the stroke are intake stroke, compression stroke, power stroke and finally exhaust stroke. To complete this operation, there is a need two cycles.

The objective of developing this engine is to improve the efficiency and reduce the emission. The six-stroke engine already developed since 1990s and many concepts of this six-stroke engine has been developed. The concept of the six - stroke is different depending on the who is the creator of the six-stroke engine. The first approach of the concept is to get an additional power and exhaust stroke of the piston in the same cylinder. For the second approach is using a second opposed piston in each cylinder, which moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle.

2.2 TWO-STROKE ENGINE

The two-stroke cycle of an internal-combustion engine has been only two-stroke (linear movements of the piston) instead of four, although the same four operations (intake, compression, power, exhaust) still occur. It is usually found in applications like lawn movers, mopeds, small outboard motors, etc.

2.2.1 Description of Two-Stroke Engine

The two-stroke internal combustion engine need two movements, which is called stroke up as a first stroke and stroke down called as second stroke. The detail operation is:

i) First Stroke – Intake and Compression

As shown in Figure 2.1, on the up to stroke the top side of the piston is compressing an air/fuel mixture in the cylinder. At the same time, the bottom side of the piston pulls another fresh charge of air/fuel mixture into the crankcase through a one-way valve called reed valve. Near the top of the stroke, the compressed air/fuel above the piston is ignited by the spark plug and begins to burn. The rapidly burning fuel expands and begins forcing the piston down.

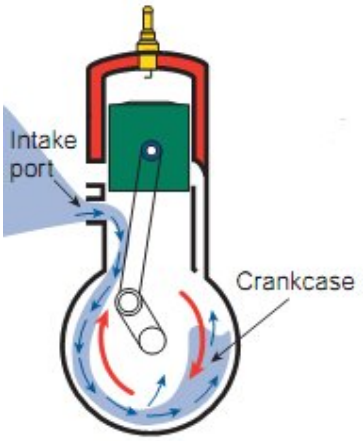

Figure 2.1: Intake and Compression

Source: Jack Erjavec (2009)

ii) Second Stroke – Power and Exhaust

As shown in Figure 2.2, on the down "power" stroke the piston is forced towards the crankcase reducing its volume and creating a positive pressure. As it continues downward travel, it starts first to uncover the exhaust ports. Exhaust gas begins to rush out of the cylinder. Then the intake ports are uncovered. The fresh air/fuel charge in the crankcase is forced into the cylinder and continues to push the remaining exhaust gases out.

The two-stroke process of purging exhausted gases from the cylinder and filling it with a fresh air/fuel charge is called scavenging. Two-stroke engine use two different scavenging methods, cross-scavenging and loop scavenging. Both differing designs have particular advantages.

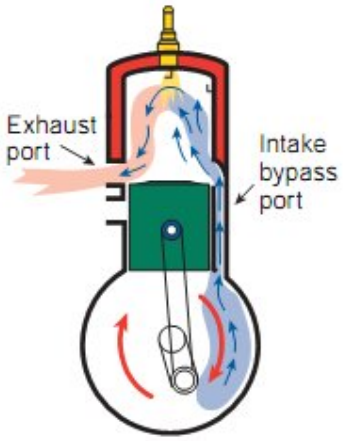

Figure 2.2: Power and Exhaust

Source: Jack Erjavec (2009)

2.2.2 Advantages and Disadvantages of Two-Stroke Engine

Advantages of two stroke engine:

- Two stroke engines do not have valves, simplifying their construction.
- Two-stroke engine fire once every revolution (four stroke engine fire once every two revolutions). This gives two-stroke engine a significant power boost.
- Two-stroke engine are lighter, and cost less to manufacture.
- Two-stroke engine has the potential for about twice the power in the same size because there are twice as many power strokes per revolution.

Disadvantages of two Stroke Engines:

- Two-stroke engines don't live as long as four-stroke engines. The lack of a dedicated lubrication system means that the parts of a two-stroke engine wear-out faster. Two-stroke engines require a mix of oil in with the gas to lubricate the crankshaft, connecting rod and cylinder walls.
- Two-stroke engine fuel can be expensive.
- Two-stroke engines do not use fuel efficiently, yielding fewer miles per liter.
- Two-stroke engines produce more pollution. From:
    - The combustion of the oil in the gas. The oil makes all two-stroke engines smoky to some extent, and a badly worn two-stroke engine can emit more oily smoke.
    - Each time a new mix of air/fuel is loaded into the combustion chamber, part of it leaks out through the exhaust port.

2.3 FOUR-STROKE ENGINE

The four-stroke engine is probably the most common engine type nowadays. It powers almost all cars and trucks.

It consists of four-stroke, one cycle operation is completed in four movement stroke of the piston. That is one cycle complete in every two revolutions of the crankshaft. Each stroke consists of 180^0 of crankshaft rotation and hence a cycle consists of 720^0 of crankshaft rotation.

In a four-stroke engine, an explosive mixture is drawn into the cylinder on the first stroke and is compressed and ignited on the second stroke; work is done on the third stroke, and the products of combustion are exhausted on the fourth stroke.

2.3.1 Description of the Four-Stroke

A four-stroke internal combustion engine has to do four things to complete one cycle as discussed below:

1. Intake/Admission stroke – In Figure 2.3, the crankshaft rotates and pulls the piston down in the cylinder which creates a partial vacuum in the cylinder. Since the intake valve is open, air is pulled through the carburetor where it also picks up fuel. At the end of the intake stroke, the camshaft rotates to a low spot on the lobe which allows the valve spring to close the intake valve.

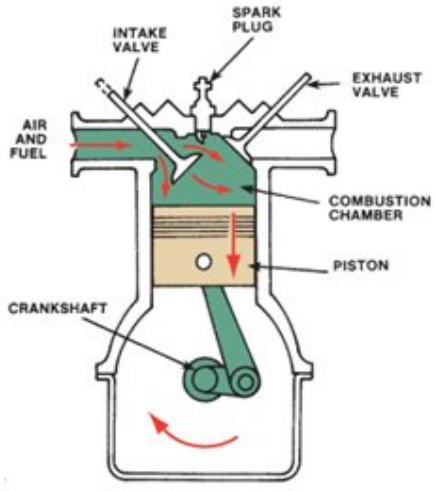

Figure 2.3: Intake/Admission Stroke

Source: Jack Erjavec(2009)

2. Compression stroke – In Figure 2.4, it compresses the fuel air mixture. During this stroke, both the intake and exhaust valve are closed.

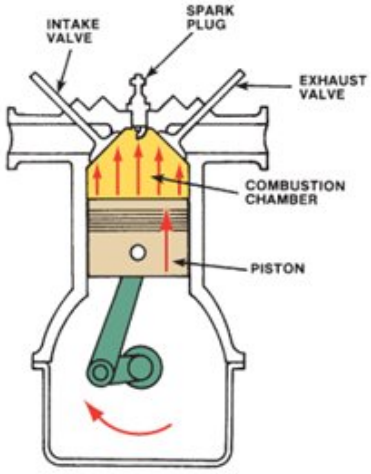

Figure 2.4: Compression Stroke

Source: Jack Erjavec (2009)

3. Power stroke – In Figure 2.5, just before the piston/crankshaft reaches top dead center (TDC), the spark plug fires and the fuel/air mixture is ignited. The heated gasses expand very rapidly and force the piston down (turning the crankshaft in the process). This is the only part of the cycle where power is produced.

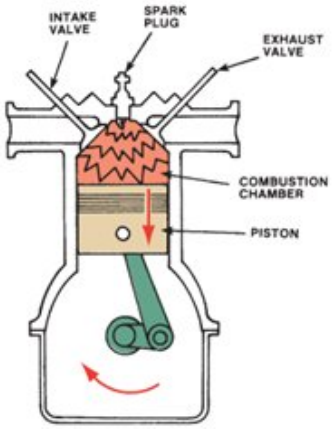

Figure 2.5: Power Stroke

Source: Jack Erjavec (2009)

4. Exhaust stroke – In Figure 2.6, at the beginning of the stroke, the exhaust valve is opened by the camshaft. When the piston is forced back up by the crankshaft, the burned fuel/mix is forced past the exhaust.

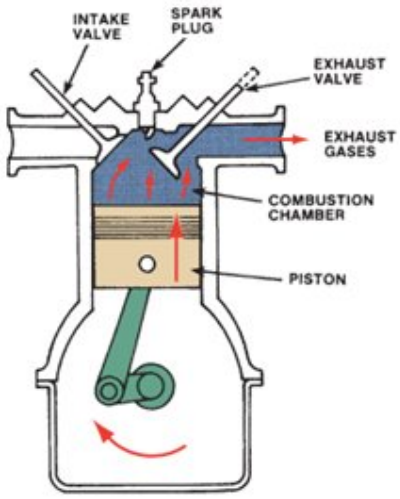

Figure 2.6: Exhaust Stroke

Source: Jack Erjavec (2009)

2.3.2 Advantage and Disadvantage of Four-Stroke Engine

Advantage of four stroke engine;

- Can produce far more power than two-stroke engine because they can be made much larger.
- Pollute less than two stroke
- More efficient use of gas.

Disadvantage of 4 stroke engine:

- Low power to weight ratio.
- More moving parts, not suitable for high speed.
- More number of stroke per circle.
- High service and overhaul cost due to more parts.

2.4 SIX-STROKE ENGINE

The six-stroke engine is a type of internal-combustion engine based on the four-stroke engine, but with additional complexity to make it more efficient and reduce emissions. Two different approaches of the six-stroke engine has been developed since the 1990s;

1. In the first approach, the engine captures the heat loss from the four-stroke Otto cycle or Diesel cycle and uses it to power an additional power and exhaust stroke of the piston in the same cylinder. The designs use either steam or air as the working fluid for the additional power stroke. The pistons in this type of six-stroke engine go up and down six times for each injection of fuel. There are two power strokes:
    - One with fuel, the other with steam or air. The currently notable designs in this class are the Crower six-stroke engine, invented by Bruce Crower in the U.S.
    - The Bajulaz engine by the Bajulaz S.A. Company of Switzerland; and the Velozeta Six-stroke engine built by the College of Engineering, at Trivandrum in India.

2. The second approach to the six-stroke engine uses a second opposed piston in each cylinder that moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle. Functionally, the second piston replaces the valve mechanism of a conventional engine but also increases the compression ratio. The currently notable designs in this class include two designs developed independently: the Beare Head engine, invented by Australian Malcolm Beare,

and the German Charge pump, invented by Helmut KottmannGriffin six-stroke engine. (S.N. Gurukulam Collage of Engineering)

The 6 stroke internal combustion engine is an advance over the existing four-stroke which employs the same principle as that of the four-stroke. The 5^{th} stroke or the second power stroke used the heat evolved in the exhaust stroke (directly or indirectly) as the heat required sudden expansion of the secondary fuel (air or water) which pushes the piston downward for the 2^{nd} power thereby rotating the crankshaft for another half cycle. As heat evolved in the 4^{th} stroke is not wasted, the requirement for a cooling system is eliminated.

Here the fuel is injected once in every three complete cycles of the crankshaft which is anytime better than four-stroke where fuel is injected once in two complete cycles of the crankshaft. It should be noted that efficiency of the six-stroke is more than the existing four-stroke. Two major types of secondary fuels used in the 5^{th} stroke are air and water. Many types of six-strokes were being designed on these two fuels of which few important types will be discussed.

Advantages of six-stroke engine;

- Thermal efficiency reaching 50%. (30% of the actual internal combustion engine).
- Fuel consumption reduced by more than 40%.
- Reduction of chemical, noise and thermal pollution.
- Two expansions (work) through six strokes.
- The cooling system is eliminated.
- Direct injection and optimal fuel combustion at every engine speed.
- Multiple fuels.

2.5 TYPES OF SIX-STROKE ENGINE

Many types of six-stroke engine were invented. The types and design depend on and who create and develop the engine. For development of six-stroke engine, many theories and applications have to. There are six the type of six-stroke engine is as discussed below:

2.5.1 Griffin Six-Stroke Engine

The key principle of the "Griffin Simplex" as shown in Figure 2.7 was a heated exhaust jacked external vaporizer, into which the fuel was sprayed. The temperature was held around 550 ºF (288 ºC), sufficient to physically vaporize the oil not to be breaking it down chemically. This fractional distillation supported the use of heavy oil fuels, the unusable tar and asphalts separating out in the vaporizer. Hot bulb ignition was used, which Griffin termed the "Catathermic Igniter", a small isolated cavity connected to the combustion chamber. The spray injector had an adjustable inner nozzle for the air supply, surrounded by annular casing for the oil, both oil and air entering at 20lbs sq in pressure, and being regulated by a governor.

Figure 2.7: Griffin Six-Stroke Engine

2.5.2 Bajulaz Six-Stroke Engine

The Bajulaz six stroke engine as shown in Figure 2.8 is similar to a regular combustion engine in the design. There are however modifications to the cylinder head, with two supplementary fixed capacity chambers, a combustion chamber and air preheating chamber above each cylinder, the injection of fuel begins an isochoric burn which increase the thermal efficiency compared to a burn in the cylinder.

The high pressure archive is then released into the cylinder to work the power or expansion stroke. Meanwhile, a second chamber which blankets the combustion chamber has its air content heated to a high degree of heat passing through the cylinder wall. This heated and pressurized air is then used to power an additional stroke of the piston. The advantages of the engine include reduction in fuel consumption by at least 40%, two expansion strokes in six-stroke, multi-fuel usage capability, and dramatic reduction in pollution.

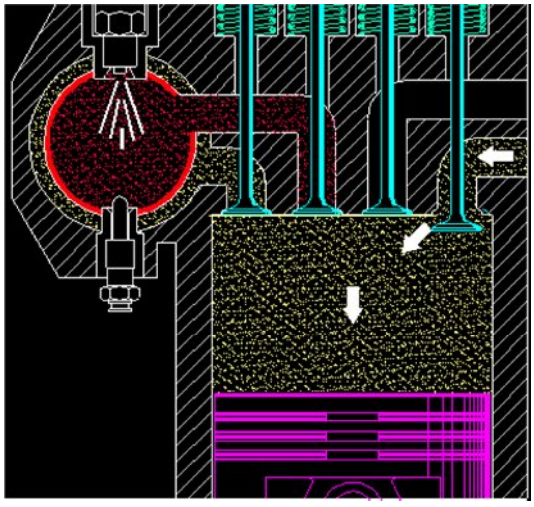

Figure 2.8: Bajulaz Six-Stroke Engine

Source: Bajulaz S.A 2007